

Mechanical Biocompatibility of Synthetic Meshes in Incisional Hernia Repair: Insights from a Clinical Dataset

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Abstract. Mechanical biocompatibility refers to the capacity of a prosthetic mesh to integrate harmoniously within host tissues while preserving adequate flexibility, elasticity, and strength. In the context of incisional hernia repair, variations in polymer composition, porosity, and stiffness may influence postoperative recovery; however, comparative clinical data remain limited.

This retrospective study analyzed 213 patients who underwent incisional hernia repair. The parameters evaluated included mesh type (polypropylene, polyester, or synthetic composite mesh), suture type (monofilament or multifilament), surgical technique (autoplastic versus alloplastic), defect diameter, and operative duration. Postoperative outcomes such as hospitalization time and complications—seroma, hematoma, infection, dehiscence, and recurrence—were also assessed. Statistical analysis was performed using the Mann–Whitney U, Kruskal–Wallis H, and Fisher's Exact tests, with a significance threshold set at $p < 0.05$. No statistically significant differences were found among the different mesh materials in terms of hospitalization length or postoperative complications ($p > 0.05$), indicating comparable levels of mechanical biocompatibility. Polyester meshes were more frequently used in smaller defects (<4 cm) and shorter procedures ($p = 0.009$), whereas polypropylene meshes predominated in larger defects. A significant relationship was identified between operative duration of approximately two hours and the occurrence of postoperative complications ($p = 0.023$).

Overall, synthetic meshes—polypropylene, polyester, and composite—showed equivalent clinical and mechanical performance in the repair of incisional hernias. These findings suggest that **defect size and intraoperative mechanical stress**, rather than the intrinsic polymer composition, play a decisive role in determining postoperative outcomes.

Keywords: mechanical biocompatibility; synthetic mesh; incisional hernia; polypropylene; polyester; synthetic composite mesh; surgical outcomes.

1. Introduction

Incisional hernia is among the most frequent long-term complications after abdominal surgery, with reported incidence rates ranging from 10% to 20%, depending on factors such as surgical technique, wound infection, and patient comorbidities including obesity and

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diabetes mellitus [1,2]. The objective of surgical repair is not only to re-establish the continuity of the abdominal wall but also to restore its mechanical stability under physiological load.

Over the past three decades, the introduction of synthetic meshes has transformed the management of abdominal wall defects, leading to a significant reduction in recurrence rates and an improvement in long-term clinical outcomes [3,4]. Despite these advances, the concept of **mechanical biocompatibility**—the ability of a prosthetic material to integrate within host tissues while preserving mechanical compliance similar to that of the native abdominal wall—remains a key determinant of postoperative success [5,6].

When the elastic or stiffness properties of the mesh differ substantially from those of the surrounding tissues, mechanical imbalance may occur, predisposing patients to excessive tension, fibrotic encapsulation, seroma formation, or even chronic pain [7].

A wide range of synthetic polymers is currently employed in incisional hernia repair, including polypropylene (PP), polyester (PES), and modern synthetic composite meshes designed with dual-surface or multilayer configurations that minimize visceral adhesions [8–10]. The biomechanical behavior of these materials—defined by parameters such as filament type, pore geometry, and surface microstructure—plays a crucial role in tissue integration and long-term biological tolerance [11]. However, comparative clinical data clarifying how these mechanical properties translate into real-world postoperative outcomes remain limited.

For this reason, the present study sought to evaluate both the mechanical and clinical biocompatibility of commonly used synthetic meshes in incisional hernia repair. By correlating mesh type, defect size, operative parameters, and postoperative complications, we aimed to identify the mechanical and procedural factors most strongly associated with prosthetic performance and clinical recovery.

2. Materials and Methods

2.1 Study Design and Population

This retrospective observational study included a total of 213 patients who underwent surgical repair for incisional hernia between 2018 and 2024. All cases were selected from hospital records after obtaining institutional ethical approval. Patients with incomplete data or combined procedures were excluded.

Demographic data (age, sex), comorbidities (diabetes mellitus, obesity, chronic pulmonary disease), and clinical characteristics (hernia size, type, and complication status) were recorded for all cases.

2.2 Surgical Technique and Mesh Classification

The patients were divided according to the type of surgical repair:

- Autoplastic repair (tissue-based closure)
- Alloplastic repair (prosthetic reinforcement using a synthetic mesh).

The meshes used were categorized into three main groups:

- Polypropylene meshes (PP) – monofilament macroporous structures with high tensile strength.
- Polyester meshes (PES) – multifilament macroporous meshes characterized by higher flexibility and elasticity.
- Synthetic composite meshes – dual-surface prostheses combining a tissue-integration layer (PP or PES) with a visceral anti-adhesion barrier (ePTFE, PVDF, or collagen-based coating).

Mesh selection and surgical positioning (sublay, onlay, or intraperitoneal) were determined by the operating surgeon according to defect size and anatomical constraints.

2.3 Evaluated Variables

The following variables were analyzed:

- Quantitative variables: patient age, operative duration, hospitalization period, defect diameter.

- Qualitative variables: sex, hernia complexity (complicated vs. uncomplicated), surgical technique (autoplastic/alloplastic), mesh type (PP, PES, composite), suture type (monofilament/multifilament), and postoperative complications (seroma, hematoma, infection, dehiscence, recurrence).

2.4 Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 25 and Microsoft Office Excel/Word 2025. Quantitative variables were tested for distribution using the Shapiro–Wilk test and expressed as means $\pm$ standard deviations or medians with interpercentile ranges, depending on distribution. Categorical variables were expressed as absolute numbers and percentages, and compared between groups using Fisher's Exact Test.

Z-tests with Bonferroni correction were applied to detail significant results from contingency tables. Quantitative variables with normal distribution were compared using the Student's t-test (based on equality of variances determined by Levene's test), while non-parametric variables were analyzed with the Mann–Whitney U or Kruskal–Wallis H tests, as appropriate.

Binary logistic regression models (univariate and multivariate) were applied to determine predictors of postoperative complications, including variables with statistically significant differences in univariate analyses. Model validity and statistical significance were verified, and each variable's predictive performance was expressed as odds ratios (OR) with 95% confidence intervals (CI) and corresponding *p*-values.

The statistical significance threshold was set at $\alpha = 0.05$.

3. Results

A total of 213 patients who underwent surgical treatment for incisional hernia were included in the analysis. The demographic and clinical characteristics of the study group are summarized in Table 1.

Table 1. Demographic and clinical characteristics

Parameter	Value
Sex (No., %) (Female)	152 (71.4%)
Age (Mean $\pm$ SD) (Median (IQR))	61.39 $\pm$ 13.48, 64 (52-70)
Complicated hernia (No., %)	131 (61.5%)
<i>Type of complication (No., %) (Total)</i>	
Strangulated hernia	49 (23%)
Incarcerated hernia	82 (38.5%)
Perforation	9 (4.2%)
Hospitalization period (Mean $\pm$ SD) (Median (IQR))	10.64 $\pm$ 3.76, 10 (8-12)
<i>Surgical technique (No., %)</i>	
Autoplastic repair	71 (33.3%)
Alloplastic repair	142 (66.7%)
<i>Mesh type (No., %)</i>	
Polypropylene mesh	128 (60.4%)
Polyester mesh	66 (31.1%)

Synthetic composite mesh (dual-surface)	18 (8.5%)
<i>Operative duration (No., %)</i>	
1 hour	50 (23.5%)
2 hours	115 (54%)
3 hours	39 (18.3%)
4 hours	9 (4.2%)
<i>Suture type (No., %)</i>	
Monofilament 0	53 (24.9%)
Monofilament 1	82 (38.5%)
Monofilament 2.0	9 (4.2%)
Multifilament	69 (32.4%)
<i>Postoperative complications (No., %)</i>	
Hematoma	3 (1.4%)
Seroma	5 (2.3%)
Wound dehiscence	2 (0.9%)
Wound infection	5 (2.3%)
Recurrence	7 (3.3%)
<i>Hernial neck size (No., %)</i>	
< 2 cm	8 (3.8%)
2–4 cm	26 (12.2%)
4 cm	179 (84%)
Type II diabetes mellitus (No., %)	27 (12.7%)

Obesity (No., %)	40 (18.8%)
Chronic pneumopathy	5 (2.3%)

3.1 Comparative Analysis between Mesh Type and Clinical Parameters

The relationship between the type of prosthetic mesh and the main clinical and mechanical parameters is summarized in Table 2. No statistically significant differences were observed between mesh materials regarding postoperative complications ($p = 0.826$) or hospitalization duration ($p = 0.415$), suggesting that polypropylene, polyester, and synthetic composite meshes exhibit comparable clinical and mechanical biocompatibility (Figure 1).

However, significant differences were found in parameters related to operative duration and defect size. Polyester meshes were more frequently applied in smaller defects (< 4 cm) and shorter procedures ($p = 0.009$), indicating easier intraoperative handling and adaptability. Conversely, polypropylene meshes as more common in large defects (> 4 cm), consistent with their superior tensile resistance and suitability for extended reinforcement.

The type of suture also correlated significantly with the mesh category ($p < 0.001$): synthetic composite meshes were most often fixed with monofilament 1 sutures, a configuration typically preferred in laparoscopic or intraperitoneal placements.

These findings indicate that the selection of mesh type is influenced primarily by mechanical considerations—particularly defect geometry and surgical accessibility—rather than differences in intrinsic biocompatibility.

Table 2. Comparative analysis between mesh type and clinical parameters.

Parameter	Test Used	<i>p</i> -Value	Statistical Significance
Mesh type ↔ Hospitalization period	Kruskal–Wallis H	0.415	Not significant
Mesh type ↔ Surgery duration	Fisher's Exact Test	0.009	Significant
Mesh type ↔ Defect size (hernial neck)	Fisher's Exact Test	< 0.001	Significant
Mesh type ↔ Suture type	Fisher's Exact Test	< 0.001	Significant
Mesh type ↔ Postoperative complications	Fisher's Exact Test	0.826	Not significant

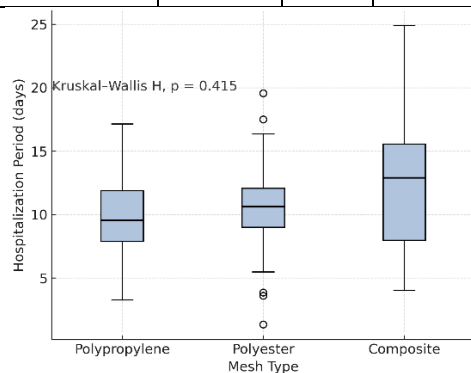


Figure 1. Distribution of hospitalization period by mesh type (polypropylene, polyester, composite).

3.2 Correlation Analysis of Mechanical and Clinical Variables

To evaluate the relationships between the main clinical and mechanical parameters, a correlation analysis was conducted using Spearman's rho and non-parametric comparative tests. The results are summarized in Table 3.

A moderate positive correlation was observed between patient age and hospitalization period ($\rho = 0.354$, $p < 0.001$), indicating that elderly patients required longer postoperative recovery. This association reflects the influence of age-related tissue elasticity and delayed healing capacity on postoperative course (Figure 2).

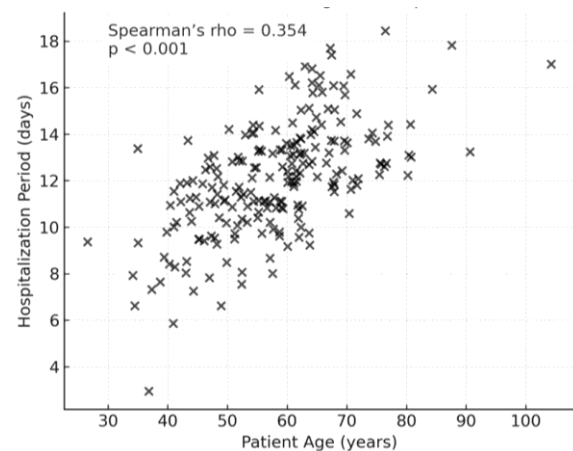


Figure 2. Scatter plot - positive correlation between patient age and hospitalization duration following incisional hernia repair.

The correlation between defect size and operative duration was also statistically significant ($p < 0.001$), confirming that larger fascial defects were associated with prolonged surgery due to the increased technical complexity and need for mechanical adaptation of the prosthetic material.

In contrast, no significant correlation was identified between hospitalization duration and other variables, such as hernia type ($p = 0.949$),

surgical technique ($p = 0.906$), or mesh type ($p = 0.415$). These findings suggest that, once mechanical tension is adequately distributed and the mesh properly fixed, the intrinsic properties of the prosthetic material (polypropylene, polyester, or composite) do not influence the length of hospital stay.

A significant association was identified between operative duration and postoperative complications ($p = 0.023$). Procedures lasting approximately two hours were most frequently associated with early seroma or wound infection, indicating that prolonged intraoperative handling and tissue stress may compromise local biocompatibility and healing dynamics.

Hospitalization ↔ Type of hernia	Mann–Whitney U	0.949	–	Not significant
Hospitalization ↔ Surgical technique	Mann–Whitney U	0.906	–	Not significant
Hospitalization ↔ Mesh type	Kruskal–Wallis H	0.415	–	Not significant

Table 3. Correlation analysis between clinical and mechanical parameters.

Variable Pair	Test / Correlation	p-Value	Correlation Strength	Statistical Significance
Age ↔ Hospitalization period	Spearman's rho = 0.354	< 0.001	Moderate positive	Significant
Defect size ↔ Operative duration	Fisher's Exact / Spearman	< 0.001	Strong association	Significant
Operative duration ↔ Postoperative complications	Fisher's Exact	0.023	Weak–moderate	Significant

The correlation matrix highlights the mechanical determinants of clinical outcome in incisional hernia repair. Longer operative duration and larger defect size were associated with increased procedural stress and higher complication rates, whereas patient age correlated primarily with recovery time rather than surgical complexity.

Importantly, no direct correlation was found between hospitalization or complication rate and the type of mesh, reinforcing the concept that polypropylene, polyester, and synthetic composite meshes exhibit comparable mechanical biocompatibility when used within appropriate tension parameters.

3.3 Operative Duration and Postoperative Complications

A statistically significant association was observed between operative duration and the occurrence of postoperative complications ($p = 0.023$). Procedures lasting two hours showed the highest complication rate, possibly reflecting a threshold where increased intraoperative manipulation and tissue handling elevate local mechanical stress and inflammatory response.

Other variables—including mesh type, surgical technique, defect size, and patient comorbidities (diabetes, obesity, chronic pulmonary disease)—did not demonstrate statistically significant associations with postoperative complications ($p > 0.05$).

These findings support the concept that operative stress and tension load, rather than polymer composition, are the major determinants of mechanical biocompatibility and postoperative stability.

3.4. Multivariate Analysis and Predictors of Postoperative Complications

To identify independent factors associated with postoperative complications, a binary logistic regression model was applied using data from 213 patients who underwent incisional hernia repair. The dependent variable was the presence of any postoperative complication (seroma, hematoma, wound infection, dehiscence, or recurrence). Predictors entered into the model included age, sex, type of prosthetic mesh (polypropylene, polyester, synthetic composite), operative duration, and comorbidities (obesity, diabetes mellitus, and chronic pulmonary disease – COPD).

The final model demonstrated good overall fit and revealed that chronic pulmonary disease (COPD) was the only independent variable significantly associated with postoperative complications. Patients with COPD had approximately 7.3-fold higher odds of developing a complication compared to those without respiratory comorbidity ($p = 0.0489$). No significant associations were observed for mesh type, operative duration (Figure 3), or surgical technique, indicating comparable clinical and mechanical biocompatibility across polypropylene, polyester, and synthetic composite meshes (Table 4).

Table 4. Binary logistic regression model for predictors of postoperative complications.

Predictor Variable	Odds Ratio (OR)	95% Confidence Interval (CI)	p-Value	Significance
Chronic pulmonary disease (COPD)	7.29	1.01 – 52.58	0.0489	Significant
Age (per year)	0.97	0.94 – 1.01	0.104	Not significant
Female sex	1.23	0.41 – 3.67	0.716	Not significant
Mesh: polyester (vs. polypropylene)	0.86	0.28 – 2.65	0.789	Not significant
Operative duration: 2 h (vs. 1 h)	0.66	0.20 – 2.14	0.489	Not significant
Operative duration: 3 h (vs. 1 h)	1.55	0.41 – 5.77	0.516	Not significant

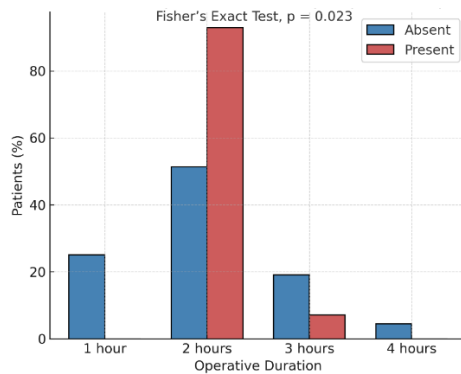


Figure 3. Association between operative duration and postoperative complications (Fisher's Exact Test, $p = 0.023$).

4. Discussion

The present study examined the mechanical biocompatibility of synthetic meshes used in incisional hernia repair by integrating clinical, surgical, and mechanical parameters obtained from a real-world patient cohort. Three main relationships were identified: (1) a moderate positive correlation between patient age and hospitalization duration, (2) no significant differences in postoperative recovery among polypropylene, polyester, and composite meshes, and (3) a statistically significant link between operative duration and the occurrence of postoperative complications. Collectively, these findings shed light on how biological factors, material properties, and intraoperative mechanical stress interact to shape clinical outcomes.

Age proved to be a relevant factor influencing postoperative recovery, as older patients tended to remain hospitalized for longer periods. This observation agrees with earlier studies showing that aging slows wound healing by reducing collagen synthesis, fibroblast activity, and overall tissue elasticity [12,13]. The slower incorporation of prosthetic materials into fibrotic tissue may therefore account for the extended recovery seen in elderly patients. Comparable results were reported by Cobb et al. (2020) and Berger et al. (2021), who highlighted the contribution of age-related biomechanical decline to mesh–tissue integration [14,15].

In contrast, the comparison of hospitalization duration among polypropylene, polyester, and composite meshes revealed no statistically significant variation ($p = 0.415$). This suggests that the three materials show similar clinical and mechanical compatibility. The finding is consistent with the reports of Deeken and Matthews (2013) and Bellows et al. (2022), who demonstrated that both polypropylene and polyester maintain stable mechanical integration when the mesh has appropriate pore size and filament morphology [16,17]. Although differences in polymer crystallinity and hydrophilicity could theoretically influence the inflammatory response [18], the lack of clinical divergence observed in this cohort supports the notion that, under optimal surgical conditions, all three mesh types behave comparably from a mechanical perspective.

A significant association was also found between operative time and postoperative complications ($p = 0.023$), particularly in surgeries lasting about two hours. Longer procedures probably reflect greater defect complexity and higher mechanical stress applied to surrounding tissues during dissection and fixation. Excessive traction and manipulation can lead to micro-injuries, edema, or transient ischemia, which may impair tissue integration and predispose to complications such as seroma or wound infection [19]. These findings reinforce the idea that the way a mesh is handled intraoperatively plays a major role in early postoperative outcomes, complementing the effect of its intrinsic material characteristics.

From a biomechanical standpoint, the study underscores that the mechanical biocompatibility of a mesh depends not solely on its polymer composition but on its ability to maintain a balanced stress–strain relationship with the host tissues. If the material is too stiff, it may generate excessive tension at the suture–mesh interface, while overly compliant meshes risk folding or loss of structural support [20]. The comparable results observed among polypropylene, polyester, and composite meshes suggest that current synthetic prostheses have achieved an optimal balance between elasticity and stability, allowing effective integration with surrounding tissues.

In summary, the results of this study indicate that synthetic meshes provide equivalent mechanical biocompatibility in incisional hernia repair. Postoperative evolution appears to depend more on patient-related factors—particularly age—and on intraoperative mechanical handling than on the specific polymer used. These insights emphasize the central role of surgical technique and individualized mesh selection according to defect size and patient physiology.

Limitations and Future Perspectives

This research has several limitations that must be considered. Because it was based on retrospective data, the study cannot fully clarify cause–effect relationships between the type of prosthetic material, operative parameters, and postoperative evolution. The number of patients included was adequate for overall statistical comparisons, yet subgroup analysis—especially in the case of composite meshes—was restricted by the relatively small sample. Moreover, mechanical biocompatibility was evaluated indirectly, using clinical variables such as hospitalization time, complication rate, and operative duration, without direct measurement of mesh elasticity or tissue strain *in vivo*.

Even with these constraints, the present work offers clinically relevant insight linking surgical outcomes to the mechanical and material properties of abdominal wall prostheses. Future studies should aim to combine clinical follow-up with quantitative mechanical assessments at the microscale. Approaches based on **atomic force microscopy, digital image correlation, or finite element modeling** could describe in real time how stress and tissue deformation evolve around implanted meshes. Collaborative, multicenter studies would also improve data reliability and facilitate the comparison of new polymer formulations and fixation methods.

Ultimately, progress in abdominal wall reconstruction depends on an interdisciplinary approach that unites surgery, materials science, and biomechanics to design prosthetic materials with improved long-term biocompatibility and mechanical resilience.

5. Conclusions

This study provides clinical evidence supporting the mechanical biocompatibility of modern synthetic meshes used in incisional hernia repair. Across polypropylene, polyester, and composite materials, no statistically significant differences were observed in postoperative recovery or complication rates, indicating comparable mechanical integration within host tissues. The findings suggest that, under optimal surgical conditions, **the polymer composition alone is not the decisive factor for clinical performance.**

Instead, postoperative outcomes were primarily influenced by patient-related factors—particularly age—and by intraoperative mechanical stress, as reflected by operative duration. The significant association between longer operative time and complication occurrence underlines the importance of surgical technique and tissue handling in preserving mesh–tissue interface stability.

From a biomechanical standpoint, these data reinforce the concept that successful prosthetic repair depends on achieving **an equilibrium between material stiffness and tissue elasticity**, ensuring adequate mechanical load transfer without excessive tension.

Future research integrating **nanoscale mechanical analysis techniques**, such as Atomic Force Microscopy (AFM) and digital image correlation, will be essential to bridge the gap between *in vitro* mechanical characterization and *in vivo* clinical performance.

In summary, **synthetic meshes currently used for incisional hernia repair demonstrate equivalent mechanical and clinical biocompatibility**, with patient biology and surgical dynamics being the main determinants of postoperative integration and stability.

Conflicts of Interest: The authors declare no conflict of interest.

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